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(71) Applicant: MITSUBISHI DENKI KABUSHIKI KAISHA
2-3, Marunouchi 2-chome
Chiyoda-ku
Tokyo 100(JP)

(72) Inventor: Shigihara, Kimio, c/o Mitsubishi Denki K. K.
Hikari Micro-ha Dev. Kenkyusho,
1 Mizuhara 4-chome
Itami-shi, Hogo 664(JP)
Inventor: Watanabe, Hitoshi, c/o Mitsubishi Denki K. K.
Hikari Micro-ha Dev. Kenkyusho,
1 Mizuhara 4-chome
Itami-shi, Hogo 664(JP)
Inventor: Kadowaki, Tomoko, c/o Mitsubishi Denki K. K.
Hikari Micro-ha Dev. Kenkyusho,
1 Mizuhara 4-chome
Itami-shi, Hogo 664(JP)
Inventor: Nishiguchi, Harumi, c/o Mitsubishi Denki K. K.
Hikari Micro-ha Dev. Kenkyusho,
1 Mizuhara 4-chome
Itami-shi, Hogo 664(JP)
Inventor: Isshiki, Kunihiko, c/o Mitsubishi Denki K. K.
Hikari Micro-ha Dev. Kenkyusho,
1 Mizuhara 4-chome
Itami-shi, Hogo 664(JP)

(74) Representative: Prüfer, Lutz H.
Patentanwalt,
Dipl.-Physiker Lutz H. Prüfer,
Dr. Habil, Jürgen Materne,
Harthauser Strasse 25d
D-81545 München (DE)

(54) **Semiconductor laser array and mounting method.**

(57) A semiconductor laser device includes a semiconductor laser array chip (3) including a plurality of active regions (4a,4b,4c), each region being driven independently, and a heat sink (2) comprising a plurality of layers comprising an insulating material having relatively high thermal conductivity (2a) and a plurality of layers comprising an insulating material having relatively low thermal conductivity (2b), which are alternately laminated in the array direction of the active regions (4a,4b,4c). The semiconductor laser array chip (3) is disposed on the heat sink (2) so that at least one of the low thermal conductivity layers (2b) of the heat sink (2) is present beneath each region between adjacent active regions of the laser array (3). Therefore, thermal crosstalks between the active regions of the laser array are reduced.

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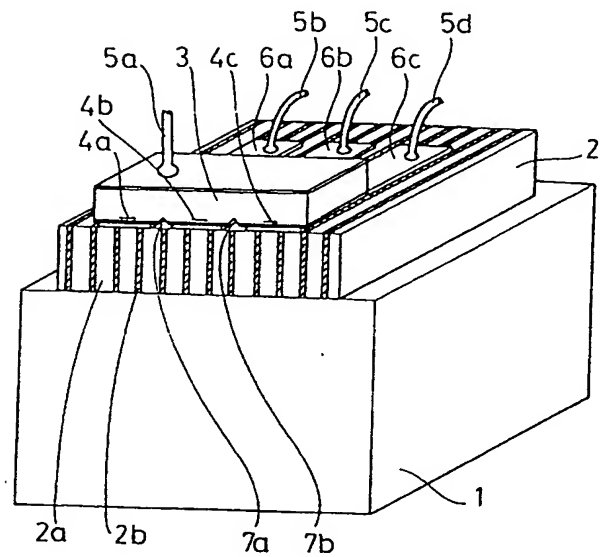
FIG.1



FIELD OF THE INVENTION

The present invention relates to a semiconductor laser device including a laser array chip in which a plurality of stripe-shaped active regions are driven independently and a heat sink on which the laser array chip is disposed and, more particularly to heat sinks that improve performance of the laser array chip. The invention also relates to a method for producing the semiconductor laser device.

BACKGROUND OF THE INVENTION

When a semiconductor laser chip is mounted on a chip-mounting part of a package, such as a metal block, a heat sink is inserted between the metal block and the laser chip to reduce thermal stress applied to the laser chip due to a difference in thermal expansion coefficients between the metal block and the laser chip.

Figure 16 is a perspective view illustrating a semiconductor laser chip mounted on a metal block via a conventional heat sink. In figure 16, reference numeral 1 designates a metal block comprising silver, copper, or the like. A heat sink 100 comprising a material of high thermal conductivity, for example, silicon or diamond, is disposed on the metal block 1. A semiconductor laser array chip 3 including three active regions 4a, 4b, and 4c, each active region producing light of a different wavelength, is disposed on the heat sink 100. Electrode patterns 6a, 6b, and 6c, which respectively correspond to the active regions 4a, 4b, and 4c of the laser chip 3, are disposed on the heat sink 100. Metal wires 5b, 5c, and 5d are connected to the electrode patterns 6a, 6b, and 6c, respectively. A metal wire 5a is connected to a common electrode of the semiconductor laser chip 3.

A description is given of the operation. Current is injected into the active regions 4a, 4b, and 4c separately from each other through the electrode patterns 6a, 6b, and 6c, respectively, which electrode patterns are separated from each other on the insulating heat sink 100, whereby the respective active regions are independently operated. Heat generated in each active region due to the laser light emission is transmitted through the heat sink 100 and the metal block 1. Since the heat sink 100 comprises a material having thermal isotropy, the heat generated in the active region is transmitted in the heat sink 100 extending not only in the vertical direction, i.e., the direction toward the metal block, but also in the horizontal direction. Therefore, in the laser array device with the conventional heat sink 100, heat generated in an active region (first active region) is unfavorably transmitted to another active region (second active region) through the heat sink 100 increasing the temperature of the second active region, whereby laser characteristics of the second active region, such as oscillation wavelength, operating current, and the like, are adversely affected by the heat from the first active region, that is, a thermal crosstalk occurs.

Figure 17 is a perspective view illustrating a semiconductor laser device including a heat sink that prevents thermal crosstalks between a plurality of active regions of a laser array, which is disclosed in Japanese Published Patent Application No. 60-175476. In figure 17, the heat sink 200 comprises a plurality of conductive heat sink layers 200a comprising copper (Cu) having a thermal conductivity of 3.9 W/cm•C and a plurality of insulating layers 200b comprising alumina (Al_2O_2) having a thermal conductivity of 0.21 W/cm•C, which are alternately laminated and adhered to each other using hard solder 200c. Preferably, the hard solder 200c is silver solder (Ag_xCu_{1-x}) or gold solder (Au_xCu_{1-x}). The semiconductor laser array chip including five active regions 4a, 4b, 4c, 4d, and 4e is disposed on the heat sink 200 so that an electrode of each active region is in contact with each heat sink layer 200a of the heat sink 200.

A description is given of the operation. Since the active regions 4a to 4e of the laser array chip 3 are in contact with the conductive heat sink layers 200a and electrically separated from each other by the insulating layers 200b, the respective active regions are independently driven by voltages applied via the corresponding conductive heat sink layers 200a. Heat generated in each active region due to the laser light emission is transmitted through the heat sink 200. If a low thermal conductivity material is used for the insulating layer 200b, the heat transmitted to the conductive heat sink layer 200a does not easily extend into the insulating layer 200b, thereby preventing a temperature rise in an active region due to heat generated in adjacent active region, i.e., the thermal crosstalk is reduced.

When the semiconductor array chip with the conventional heat sink comprising alternating conductive layers and insulating layers is mounted on a metal block of a package to complete a semiconductor laser device, an insulator should be inserted between the metal block and the heat sink or the laser chip should be mounted on an insulator block instead of the metal block to prevent a short circuit between adjacent active regions of the laser array chip, resulting in a complicated fabrication. In addition, since the material of the semiconductor laser chip is different from the materials of the heat sink, thermal stress is applied to the laser chip, adversely affecting the laser characteristics. Furthermore, the fabrication of the conventional heat

sink including adhering the high thermal conductivity material and the low thermal conductivity material using the hard solder takes much time and labor, and it is difficult to fabricate the heat sink with high dimensional precision.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a semiconductor laser device that prevents thermal crosstalks between active regions of the laser array.

It is another object of the present invention to provide a semiconductor laser device that prevents thermal crosstalks between active regions of the laser array and reduces the stress generated in the semiconductor laser array chip.

It is still another object of the present invention to provide a relatively simple method for producing a semiconductor laser device which prevents thermal crosstalks between active regions of the laser array, providing good product yield.

Other objects and advantages of the present invention will become apparent from the detailed description given hereinafter; it should be understood, however, that the detailed description and specific embodiment are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

According to a first aspect of the present invention, a semiconductor laser device includes a semiconductor laser array chip including a plurality of active regions, each region being driven independently, and a heat sink comprising a plurality of layers comprising an insulating material having relatively high thermal conductivity and a plurality of layers comprising an insulating material having relatively low thermal conductivity, which are alternately laminated in the array direction of the active regions. The semiconductor laser array chip is disposed on the heat sink so that at least one of the low thermal conductivity layers of the heat sink is present beneath each region between adjacent active regions of the laser array. Therefore, thermal crosstalks between the active regions of the laser array are reduced.

According to a second aspect of the present invention, a semiconductor laser device includes a semiconductor laser array chip including a plurality of stripe-shaped active regions, each region being driven independently, and a heat sink comprising a plurality of layers comprising an insulating material having a high thermal conductivity and a plurality of layers comprising an insulating material having a low thermal conductivity, which are alternately laminated in the array direction of the active regions. Thicknesses of the respective layers of the heat sink are determined so that a thermal expansion coefficient of the whole heat sink is equivalent to a thermal expansion coefficient of a principal material of the semiconductor laser array chip. The semiconductor laser array chip is disposed on the heat sink so that at least one of the low thermal conductivity layers of the heat sink is present beneath each region between adjacent active regions of the laser array. Therefore, thermal crosstalks between the active regions of the laser array are reduced, and the stress generated in the semiconductor laser chip is reduced, thereby improving characteristics of the semiconductor laser device.

According to a third aspect of the present invention, a method for producing a semiconductor laser device includes forming a heat sink by alternately depositing a material having high thermal conductivity and a material having low thermal conductivity using CVD, sputtering, vacuum deposition, or the like. Therefore, the heat sink is easily produced with high dimensional precision.

According to a fourth aspect of the present invention, a semiconductor laser device includes a semiconductor laser array chip including a plurality of stripe-shaped active regions, each region being driven independently, and a heat sink including a plurality of stripe grooves having a prescribed depth, which are periodically disposed in the array direction of the active regions of the laser array chip. The semiconductor laser array chip is disposed on the heat sink so that each stripe groove is present beneath each region between adjacent active regions. The depth of the stripe groove is determined so that a distance from one of the active regions of the laser array chip to adjacent active region along the periphery of the stripe groove is longer than a distance from the surface of the heat sink to the rear surface thereof. In this structure, since the heat conductivity of the heat sink in the horizontal direction is low, thermal crosstalks between the active regions of the laser array chip are reduced.

According to a fifth aspect of the present invention, a semiconductor laser device includes a semiconductor laser array chip including a plurality of stripe-shaped active regions, each region being driven independently, and a heat sink including a plurality of stripe-shaped regions of low thermal conductivity having a prescribed depth from the surface of the heat sink, which are periodically disposed in the array direction of the active regions. The semiconductor laser array chip is disposed on the heat sink so that each low thermal conductivity region is present beneath each region between adjacent active regions. The depth

of the low thermal conductivity region is determined so that a distance from one of the active regions of the semiconductor laser chip to adjacent active region along the periphery of the low thermal conductivity region is longer than a distance from the surface of the heat sink to the rear surface thereof. In this structure, since the heat conductivity of the heat sink in the horizontal direction is low, thermal crosstalks between the active regions of the laser array chip are reduced.

According to a sixth aspect of the present invention, a semiconductor laser device includes a semiconductor laser array chip including a plurality of stripe-shaped active regions, each region being driven independently, and a heat sink comprising a polycrystalline layer including columnar or fiber grains. The semiconductor laser array chip is disposed on a surface of the heat sink, which surface is perpendicular to the length of the grain. In this structure, the heat conductivity in the longitudinal direction of the grain is high while the heat conductivity in the horizontal direction is low because voids existing among the grains impede the heat transmission, thereby reducing thermal crosstalks between the active regions of the laser array chip.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view illustrating a semiconductor laser devlce in accordance with a first embodiment of the present invention;

Figures 2(a)-2(d) are perspective views illustrating a method for producing a heat sink included in the semiconductor laser device of figure 1;

Figure 3 is a perspective view illustrating a semiconductor laser device in accordance with a second embodiment of the present invention;

Figure 4 is a perspective view illustrating a heat sink included in a semiconductor laser device in accordance with a third embodiment of the present invention;

Figure 5 is a schematic diagram illustrating a heat sink included in a semiconductor laser device in accordance with a fourth embodiment of the present invention;

Figure 6 is a perspective view illustrating a semiconductor laser device in accordance with a fifth embodiment of the present invention;

Figure 7 is a perspective view illustrating a semiconductor laser device in accordance with a sixth embodiment of the present invention;

Figure 8 is an enlarged view of a portion of the semiconductor laser device of figure 6;

Figures 9(a)-9(c) are diagrams illustrating a method for producing a heat sink included in the semiconductor laser device of figure 6;

Figure 10 is a perspective view illustrating a semiconductor laser device in accordance with a seventh embodiment of the present invention;

Figure 11 is a perspective view illustrating a semiconductor laser device in accordance with an eighth embodiment of the present invention;

Figure 12 is a perspective view illustrating a semiconductor laser device in accordance with a ninth embodiment of the present invention;

Figures 13(a)-13(b) are diagrams illustrating a heat sink included in the semiconductor laser device of figure 14;

Figure 14 is a perspective view illustrating a semiconductor laser device in accordance with a tenth embodiment of the present invention;

Figures 15(a)-15(b) are diagrams illustrating a heat sink included in the semiconductor laser device of figure 14;

Figure 16 is a perspective view illustrating a semiconductor laser device including a heat sink according to the prior art; and

Figure 17 is a perspective view illustrating a semiconductor laser device including a heat sink according to the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a perspective view illustrating a semiconductor laser device in accordance with a first embodiment of the present invention. In figure 1, reference numeral 1 designates a metal block comprising silver, copper, or the like. A heat sink 2 is disposed on the metal block 1. The heat sink 2 comprises a plurality of heat-radiating layers 2a comprising a first insulating material and having a relatively high thermal conductivity and a plurality of heat-insulating layers 2b comprising a second insulating material and having a relatively low thermal conductivity, which layers 2a and 2b are alternately laminated. Preferably, the first

insulating material is diamond having a thermal conductivity of 20W/cm•C and the second insulating material is SiO_2 having a thermal conductivity of 0.014W/cm•C. A semiconductor laser array chip 3 including three active regions 4a, 4b, and 4c is disposed on the heat sink 2. Electrode patterns 6a, 6b, and 6c corresponding to the active regions 4a, 4b, 4c, respectively, are disposed on the heat sink 2. Metal wires 5b, 5c, and 5d are connected to the electrode patterns 6a, 6b, and 6c, respectively, and a metal wire 5a is connected to a common electrode of the semiconductor laser chip 3. The active regions 4a, 4b, and 4c are electrically isolated from each other by stripe grooves 7a and 7b.

A description is given of the operation. The heat sink 2 employed in the semiconductor laser device of figure 1 comprises the heat-radiating layers (diamond layers) 2a and the heat-insulating layer (SiO_2 layers) 2b which are alternately laminated in the array direction of the active regions. Therefore, heat generated in each of the active regions 4a, 4b, and 4c is transmitted to the metal block 1 through the heat-radiating layer 2a. On the other hand, the heat conductivity of the heat sink 2 in the horizontal direction is poor because of the periodic presence of the heat-insulating layers 2b, so that the heat does not extend in the horizontal direction. As a result, heat transmission between adjacent active regions through the heat sink is reduced, providing a semiconductor laser array with less thermal crosstalk.

According to the first embodiment of the present invention, since the high thermal conductivity layers 2a and the low thermal conductivity layers 2b, which are alternately laminated in the array direction of the active regions of the laser chip 3 to constitute the heat sink 2, comprise insulating materials, crosstalks between the active regions are reduced. In addition, when the laser array chip with the heat sink is disposed on a metal block, no short circuit occurs between adjacent active regions of the laser array. In addition, fabrication process of the semiconductor laser device is simplified.

Among insulating materials, diamond, which is employed in the first embodiment of the present invention, has a much higher thermal conductivity than copper (thermal conductivity: 3.9W/cm•C) and silver (thermal conductivity: 4.28W/cm•C) which are conductive materials having relatively high thermal conductivities. When such a high thermal conductivity insulating material is used as the heat-radiating layer 2a, a heat sink with improved heat-radiating efficiency is achieved.

While in the above-described first embodiment diamond and SiO_2 are used as materials of the heat-radiating layer 2a and the heat-insulating layer 2b, respectively, the materials are not restricted thereto. For example, CBN (Cubic Boron Nitride) having a thermal conductivity of 6W/cm •C) may be used as the material of the heat-radiating layer.

Figures 2(a)-2(d) are perspective views illustrating a method for producing the heat sink of the semiconductor laser device of figure 1. In the figures, reference numeral 20 designates an SiO_2 substrate, numeral 21 designates diamond layers, and numeral 22 designates SiO_2 layers.

Initially, as illustrated in figure 2(a), diamond, which is an insulating material having a relatively high thermal conductivity, is deposited on an SiO_2 substrate 20 to a prescribed thickness by CVD. Then, as illustrated in figure 2(b), SiO_2, which is an insulating material having a relatively low thermal conductivity, is deposited on the diamond layer 21 to a prescribed thickness by sputtering. The alternating growths of the diamond layer 21 and the SiO_2 layer 22 are repeated to form a laminated structure of a prescribed thickness as shown in figure 2(c). Thereafter, as illustrated in figure 2(d), the laminated structure is divided into a plurality of blocks, each block having desired size and shape, using a dicing saw or a laser saw. Then, electrode patterns are produced on the surface of each block to complete a heat sink for a semiconductor laser device.

In this method, a plurality of heat sinks having uniform characteristics are easily produced from a large-sized block, improving the production yield.

During producing the laminated structure by CVD or sputtering, thicknesses of the respective layers are easily controlled, so that the dimensional precision is significantly improved as compared with the conventional method of adhering thin films using hard solder.

While in the above-described method the diamond layer 21 is grown by CVD and the SiO_2 layer 22 is grown by sputtering, both layers may be successively grown by CVD in a CVD apparatus. In addition, the growth methods of the respective materials are not restricted to CVD and sputtering. For example, vacuum deposition may be employed.

Figure 3 is a perspective view illustrating a semiconductor laser device including an improved heat sink in accordance with a second embodiment of the present invention. In figure 3, the same reference numerals as in figure 1 designate the same or corresponding parts.

In the semiconductor laser device shown in figure 1 according to the first embodiment of the present invention, the heat-insulating layers 2b are present beneath the active regions 4a to 4c of the semiconductor laser array chip 3 while the heat-radiating layers 2a are present beneath the grooves for isolation 7a and 7b.

In order to improve the performance of the heat sink of the first embodiment, an increase in the heat-radiating efficiency of the heat sink and a decrease in crosstalks between adjacent active regions of the laser array should be achieved. To increase the heat-radiating efficiency of the heat sink, portions of the heat sink beneath the respective active regions of the laser array should be formed of the high thermal conductivity material. To decrease crosstalks between the active regions of the laser array, the low thermal conductivity layers of the heat sink disposed beneath regions between adjacent active regions should be thick.

The heat sink according to this second embodiment shown in figure 3 satisfies the above-described conditions. More specifically, in figure 3, each of the active regions 4a, 4b, and 4c of the laser array is disposed on the insulating layer 2a having a relatively high thermal conductivity and the same width as the active region, and each of the grooves for isolation 7a and 7b is disposed on the insulating layer 2b having a relatively low thermal conductivity and the same width as the groove. In this structure, the heat-radiating efficiency is further improved and the crosstalks between the active regions are further reduced as compared with the semiconductor laser device of figure 1.

Figure 4 is a perspective view illustrating a heat sink in accordance with a third embodiment of the present invention. In figure 4, reference numeral 23 designates a layer having a relatively high thermal conductivity and a thickness d1, numeral 24 designates a layer having a relatively low thermal conductivity and a thickness d2. Materials and thermal expansion coefficients of the layers 23 and 24 are different from each other. In this third embodiment, the thickness d1 of the high thermal conductivity layer 23 and the thickness d2 of the low thermal conductivity layer 24 are precisely controlled to reduce stress applied to a semiconductor laser chip disposed on the heat sink.

An expansion ΔL of the heat sink 2 when the temperature thereof rises by 1°C is represented as follows:

$$\Delta L = m\alpha a\ d1 + n\alpha b\ d2 \quad (1)$$

where m is the number of the high thermal conductivity layers 23, n is the number of the low thermal conductivity layers 24, αa and αb are the thermal expansion coefficients of the layers 23 and 24, respectively, and L is the width of the heat sink 2.

Therefore, the expansion of the heat sink 2 per a unit length is represented as follows:

$$\Delta L/L = (m\alpha a\ d1 + n\alpha b\ d2)/L \quad (2)$$

When the thicknesses d1 and d2 of the respective layers 23 and 24 are set so that $\Delta L/L$ is equal to the thermal expansion coefficient αLD of the semiconductor laser chip, no stress is applied to the laser chip.

For example, the high thermal conductivity layers 23 comprise diamond having thermal conductivity of 20 W/cm•C and thermal expansion coefficient of $3 \times 10^{-6} \cdot C^{-1}$, the low thermal conductivity layers 24 comprise silver having thermal conductivity of 4.28 W/cm•C and thermal expansion coefficient of $11.8 \times 10^{-6} \cdot C^{-1}$, and the semiconductor laser chip comprises GaAs having thermal expansion coefficient of $6.63 \times 10^{-6} \cdot C^{-1}$. In this case, if the thickness of each diamond layer d1 is 100 microns, the number of the diamond layers m is ten, the thickness of each silver layer d2 is 76.1 microns, and the number of the silver layers n is eleven, the equation (2) is solved as follows:

$$L/L = (10 \times 2.3 \times 10^{-6} \times 0.1 + 11 \times 11.8 \times 10^{-6} \times 0.0761)/(10 \times 0.1 + 11 \times 0.0761)$$

$$\fallingdotseq 6.63 \times 10^{-6}$$

Thus, the thermal expansion coefficient of the heat sink 2 is equal to the thermal expansion coefficient of GaAs.

In this third embodiment, the thickness d1 of the high thermal conductivity layer 23 and the thickness d2 of the low thermal conductivity layer 24 are calculated according to the primary approximate calculation

in which only materials of the layers 23 and 24 and the laser chip are considered. If the thicknesses d1 and d2 are calculated more precisely according to a calculation in which the thermal expansion coefficient of the metal block 1, the structure of the laser chip, and the like are also considered, the stress applied to the laser chip is further reduced.

In producing the heat sink of this embodiment, the high thermal conductivity layers 23 and the low thermal conductivity layers 24 are alternately grown by CVD, sputtering, or vacuum deposition, and the laminated structure thus obtained is divided into a plurality of blocks using a dicing saw or a laser saw. While producing the laminated structure by CVD, sputtering, or vacuum deposition, it is very easy to control the thickness of each layer and, therefore, these methods are effective particularly when precise control of the thickness of each layer is needed like in this third embodiment of the present invention.

While in the above-described third embodiment diamond which is a dielectric material is employed for the high thermal conductivity layer 23 and silver which is a conductive material is employed for the low thermal conductivity layer 24, both layers 23 and 24 may comprise insulating materials appropriately selected. In this case, no short circuit occurs between the active regions of the semiconductor laser array chip disposed on the heat sink.

Figure 5 is an enlarged view of a portion of a semiconductor laser device in accordance with a fourth embodiment of the present invention, in which the heat sink of the above-described third embodiment shown in figure 4 is further improved.

In this fourth embodiment, the high thermal conductivity layers 23 disposed beneath the active regions 4 are thick and the low thermal conductivity layers 24 disposed beneath the isolation grooves 7a and 7b are thick, and the thicknesses of the respective layers are determined so that the thermal expansion coefficient of the whole heat sink in the horizontal direction is equal to the thermal expansion coefficient of the semiconductor laser chip. In this embodiment, in addition to the reduction in stress applied to the laser chip, further increase in the heat-radiating efficiency of the heat sink and further reduction in the crosstalks between the active regions of the laser array are achieved.

Figure 6 is a perspective view illustrating a semiconductor laser device in accordance with a fifth embodiment of the present invention. In figure 6, reference numeral 1 designates a metal block. A heat sink 2 comprising an insulating material, such as silicon, and having three stripe V grooves 8 is disposed on the metal block 1. A laser array chip 3 including a plurality of active regions 4a to 4d, each active region producing light of a different wavelength, is disposed on the heat sink 2. Electrode patterns 6a to 6d corresponding to the active regions 4a to 4d, respectively, are disposed on the heat sink 2. Metal wires 5b to 5e are connected to the electrode patterns 6a to 6d, respectively, and a metal wire 5a is connected to a common electrode of the semiconductor laser chip 3.

A description is given of the operation. Figure 8 is an enlarged view of a portion of the structure shown in figure 6. In figure 8, the same reference numerals as in figure 6 designate the same or corresponding parts. In this fifth embodiment, the V groove 8 is present beneath a region of the laser chip 3 between adjacent active regions 4a and 4b, so that air is present beneath that region. Since thermal conductivity of air is lower than thermal conductivity of silicon constituting the heat sink, heat, which is generated in the active region 4a and transmitted in the heat sink toward the active region 4b, flows around the air region along the side walls of the V groove 8. Accordingly, if the thickness of the heat sink 2, i.e., the distance L1 from the surface of the heat sink to the surface of the metal plate 1 is shorter than the distance L2 between the adjacent active regions 4a and 4b along the V groove 8, the transmission of heat from the active region 4a to the active region 4b through the heat sink 2 is effectively suppressed, reducing the thermal crosstalk between the active regions 4a and 4b.

In the above-described fifth embodiment, the region contributing to the heat radiation of the heat sink is trapezoid in cross section in which the width increases with the distance from the active region. In this case, heat radiation from the laser chip is improved as compared with the rectangular heat-radiating region because heat from the active region flows radiately in that region.

Figures 9(a)-9(c) illustrates a method for producing the heat sink 2 of figure 6.

Initially, a (100) surface of an insulating silicon substrate 25 is metallized to form a metal layer 60 and a photoresist 61 is deposited on the metal layer 60. Then, the metal layer 60 and the photoresist 61 are patterned as shown in figure 9(a) using conventional photolithography and etching. Using this pattern as a mask, the silicon substrate 25 is etched by an etchant comprising KOH, water, and isopropyl alcohol, to form V grooves 80 in which (111) surfaces are exposed as shown in figure 9(b). Since the gradient of the (111) surface to the (100) surface is about 54.7 , if the width W of the groove 80 is 100 microns, the depth D of the groove is about 71 microns. After the etching, the photoresist 61 is removed as shown in figure 9-(c), followed by dicing to cut the substrate 25 in a desired size, completing the heat sink 2. The metal layers 60 serve as the electrode patterns 6a to 6d.

In figure 8, when the interval L3 between adjacent active regions 4a and 4b of the semiconductor laser array chip 3 is 200 microns, a silicon substrate 150 microns thick is used for the heat sink, and the V grooves 80 each having an aperture width L4 of 100 microns are formed in the substrate according to the method of figures 9(a)-9(c), the depth L5 of each groove 80 becomes about 71 microns as described above, whereby the distance L2 between the active regions 4a and 4b along the V groove 8 is sufficiently longer than the distance L1 from the active region to the surface of the metal layer 1.

While in the above-described fifth embodiment the heat sink substrate comprises insulating silicon, it may comprise other insulating materials.

Figure 7 is a perspective view illustrating a semiconductor laser device in accordance with a sixth embodiment of the present invention. In figure 7, the V grooves 8 do not reach the rear surface 2a of the heat sink 2, and only the electrode patterns 6a to 6d are separated from each other, whereby mechanical strength of the heat sink is increased as compared with the fifth embodiment of the present invention.

Figure 10 is a perspective view illustrating a semiconductor laser device in accordance with a seventh embodiment of the present invention. In figure 10, the grooves 8 penetrate through the heat sink substrate, so that the trapezoid heat-radiating regions of the heat sink are separated from each other. Also in this embodiment, the same effects as described in the fifth embodiment is be attained.

In the above-described seventh embodiment, since the V grooves 8 are formed from the front surface 2a to the rear surface 2a of the heat sink 2, so that the heat sink 2 is completely divided into four blocks, resulting in a complicated fabrication process. Figure 11 is a perspective view illustrating a semiconductor laser device in accordance with an eighth embodiment of the present invention. In this eighth embodiment, the V grooves 8 do not reach the rear surface 2b of the heat sink and only the electrode patterns 6a to 6d are separated from each other, so that the heat sink 2 is formed as one block in a relatively simple process.

Figure 12 is a perspective view illustrating a semiconductor laser device in accordance with a ninth embodiment of the present invention. In figure 12, the heat sink 2 includes three impurity diffused regions 11 which are formed by a selective diffusion of impurity into a heat sink substrate 25 comprising insulating silicon.

A description is given of the operation. A reduction in thermal crosstalks between active regions of the semiconductor laser array according to this ninth embodiment is based on the same principle as described in the fifth embodiment. That is, in this ninth embodiment, a region between adjacent active regions of the laser array is disposed on each impurity diffused region 11 formed in the heat sink 2. It is well known that the impurity diffused region produced in the silicon substrate has lower thermal conductivity than the other region of the substrate in which no impurity is diffused. Therefore, in figure 12, heat, which is generated in the active region 4a and transmitted toward the active region 4b, flows around the impurity diffusion region 11, along the diffusion front. Accordingly, if the distance from the active region 4a to the surface of the metal block 1 is shorter than the distance between the active regions 4a and 4b along the diffusion front of the impurity diffused region 11, the heat transmission from the active region 4a to the active region 4b through the heat sink 2 is effectively suppressed, reducing the thermal crosstalk between those regions.

Figures 13(a) and 13(b) illustrate a method for producing the heat sink 2 of figure 12.

Initially, a metal film comprising Au or the like, an insulating film, or a conductive film is deposited over the surface of the heat sink substrate 25 comprising insulating silicon. Then, the film is selectively etched leaving portions, each portion having the same width as each element of the laser array 3, resulting in a mask for selective diffusion 9 with apertures 10 (figure 13(a)).

Then, an impurity, for example, phosphorus or boron, is diffused into the silicon substrate 25 using the mask 9 having the apertures 10, producing impurity diffused regions 11 at equal spaces to a prescribed depth 11 (figure 13(b)).

Thereafter, metal or solder 12 is deposited on both surfaces of the heat sink substrate 25, whereby the heat sink is easily soldered to the laser array chip 3, a mount, or a package. When the diffusion mask 9 comprises metal, the metal or solder film 12 is dispensed with, simplifying the production process. The metal or solder film 12 may be deposited after removing the diffusion mask 9.

In fabricating the semiconductor laser device, as shown in figure 12, the active regions 4a to 4d of the laser array chip 3 are positioned on the regions of the heat sink 2 where the impurity diffused regions 11 are absent.

In figure 12, when a silicon substrate 150 microns thick is used as the heat sink substrate 25 and the impurity diffused regions 11 about 80 microns deep are formed using the diffusion mask 9 having apertures about 10 microns wide according to the above-described method, the distance between the active regions 4a and 4b around the impurity diffused region 11 is sufficiently longer than the distance from the active region 4a to the surface of the metal block 1.

While in the above-described ninth embodiment the heat sink substrate comprises insulating silicon, it may comprise other insulating materials, such as SiC or AlN.

In place of the impurity diffused regions 11, oxide regions may be formed by thermally oxidizing portions of the heat sink substrate. For example, when portions of the heat sink substrate comprising insulating silicon are thermally oxidized to form relatively low thermal conductivity regions comprising SiO_2, since the thermal conductivity of SiO_2 is only 0.19 W/cm • C while the thermal conductivity of silicon is 1.5 W/cm • C, the same effects as described above are attained.

Figure 14 is a perspective view illustrating a semiconductor laser device in accordance with a tenth embodiment of the present invention. In figure 14, the same reference numerals as shown in figure 1 designate the same or corresponding parts. Reference numeral 26 designates a heat sink having an anisotropy of thermal conductivity and numeral 27 designates an SiO_2 film deposited on the heat sink 26.

Figure 15(a) is a schematic diagram illustrating different internal structures of a copper film formed by sputtering at various Ar gas pressures and various growth temperatures, and figure 15(b) is a cross section of a copper film formed under the condition at the point 3B of figure 15(a), which are disclosed in Journal of Science Technology, Vol.11, No.4, pp 666-670.

When the Ar gas pressure (mTorr) and the growth temperature (T/TM where T is the growth temperature and TM is the melting point) are varied during forming a copper film by sputtering, the internal structure of the copper film varies as shown in figure 15(a). Under the condition of the point 3B, i.e., at the Ar gas pressure of 30 mTorr (=3.9 Pa) and the growth temperature T/TM of 0.2 (since the melting point of copper is 1356[K], the temperature T is 271.2[K]), a porous polycrystalline film in which a plurality of voids are present between long and narrow grains is formed.

The thermal conductivity of the porous polycrystalline film is high in the longitudinal direction of the grain, but it is low in the direction perpendicular to the length of the grain because the voids impede the heat transmission. That is, the polycrystalline film has an anisotropy in the thermal conductivity.

In the tenth embodiment of the present invention shown in figure 14, such a porous polycrystalline film having an anisotropy in the heat conductivity is employed as the heat sink 26. In production, the polycrystalline copper film grown under the above-described conditions is formed into the heat sink 26 about 100 microns thick having a surface perpendicular to the length of the grain, and the SiO_2 film 27 is deposited on the surface of the heat sink 26 and, thereafter, the electrode patterns 6a to 6c are formed on the SiO_2 film 27. Since the growth rate under the above-described conditions is about 0.2 micron/min, the polycrystalline film about 100 microns thick is formed in about eight hours. Although each single grain of the polycrystalline film is not always as long as 100 microns, sufficient anisotropy in the heat conductivity is achieved even if the film includes broken grains.

In this embodiment, heat generated in each active region is transmitted to the metal block 1 through the grains. Since the voids impede the heat transmission in the horizontal direction, thermal crosstalks between the active regions through the heat sink are reduced.

While in the tenth embodiment the polycrystalline film comprises copper, it may comprise other metals or insulating materials.

In figure 14, the SiO_2 film 27 disposed on the heat sink 26 is for preventing short circuit between adjacent active regions of the laser array when the heat sink 26 comprises a conductive material like copper. When the heat sink 26 comprises an insulating material, the SiO_2 film 27 is dispensed with.

While in the above-described embodiments junction-down mounting is employed when the semiconductor laser chip is mounted on the heat sink, junction-up mounting may be employed. In this case, although the heat-radiating efficiency is lower than that of the laser device fabricated by the junction-down mounting, reduction in crosstalks is achieved.

While in the above-described embodiments the semiconductor laser array chip including a plurality of stripe-shaped active regions, in which each active region is independently driven, is mounted on the heat sink, a plurality of semiconductor laser chips each having a stripe-shaped active region may be mounted on the heat sink. Also in this case, the same effects as described above are achieved.

While in the above-illustrated embodiments the semiconductor laser array includes three or four active regions, the number of the active regions may be two, five or more.

As is evident from the foregoing description, according to the present invention, a heat sink, on which a semiconductor laser array chip including a plurality of active regions is disposed, comprises a plurality of layers comprising an insulating material having relatively high thermal conductivity and a plurality of layers comprising an insulating material having relatively low thermal conductivity, which are alternately laminated in the array direction of the active regions, and the laser array chip is disposed on the heat sink so that at least one of the low thermal conductivity layers of the heat sink is present beneath each region between adjacent active regions of the laser array. Therefore, thermal crosstalks between the active regions of the

laser array are reduced.

According to the present invention, a heat sink, on which a semiconductor laser array chip including a plurality of active regions is disposed, comprises a plurality of layers comprising an insulating material having a high thermal conductivity and a plurality of layers comprising an insulating material having a low thermal conductivity, which are alternately laminated in the array direction of the active regions. Thicknesses of the respective layers of the heat sink are determined so that a thermal expansion coefficient of the whole heat sink is equivalent to a thermal expansion coefficient of a principal material of the semiconductor laser array chip. The semiconductor laser array chip is disposed on the heat sink so that at least one of the low thermal conductivity layers of the heat sink is present beneath each region between adjacent active regions of the laser array. Therefore, thermal crosstalks between the active regions of the laser array are reduced and the stress generated in the semiconductor laser chip is reduced, thereby improving characteristics of the semiconductor laser device.

In addition, according to the present invention, a heat sink for a semiconductor laser device is produced by alternately depositing a material having relatively high thermal conductivity and a material having relatively low thermal conductivity using CVD, sputtering, vacuum deposition, or the like. Therefore, the heat sink is easily produced with high dimensional precision.

Furthermore, according to the present invention, a heat sink, on which a semiconductor laser array chip including a plurality of active regions is disposed, includes a plurality of stripe grooves having a prescribed depth, which are periodically disposed in the array direction of the active regions of the laser array chip. The semiconductor laser array chip is disposed on the heat sink so that each stripe groove is present beneath each region between adjacent active regions. In this structure, since the heat conductivity of the heat sink in the horizontal direction is low, thermal crosstalks between the active regions of the laser array chip are reduced.

Furthermore, according to the present invention, a heat sink, on which a semiconductor laser array chip including a plurality of active regions is disposed, includes a plurality of stripe-shaped low thermal conductivity regions having a prescribed depth, which are periodically disposed in the array direction of the active regions. The semiconductor laser array chip is disposed on the heat sink so that each low thermal conductivity region is present beneath each region between adjacent active regions. In this structure, since the heat conductivity of the heat sink in the horizontal direction is low, thermal crosstalks between the active regions of the laser array chip are reduced.

Furthermore, according to the present invention, a heat sink, on which a semiconductor laser array chip including a plurality of active regions is disposed, comprises a polycrystalline layer including columnar or fiber grains. The semiconductor laser array chip is disposed on a surface of the heat sink perpendicular to the length of the grain. In this structure, the heat conductivity in the longitudinal direction of the grain is high while the heat conductivity in the horizontal direction is low because voids existing among the grains impede the heat transmission, thereby reducing thermal crosstalks between the active regions of the laser array chip.

Claims

1. A semiconductor laser device comprising a semiconductor laser array chip (3) including a plurality of stripe-shaped active regions (4a,4b,4c), each active region being driven independently, and a heat sink (2) on which said semiconductor laser array chip (3) is disposed, wherein:

   said heat sink (2) comprising a plurality of layers comprising an insulating material having relatively high thermal conductivity (2a) and a plurality of layers comprising an insulating material having relatively low thermal conductivity (2b), which are alternately laminated in the array direction of said active regions (4a,4b,4c); and

   said semiconductor laser array chip (3) being disposed on said heat sink (2) so that at least one of said layers having relatively low thermal conductivity (2b) is present beneath each region between adjacent active regions.

2. A semiconductor laser device comprising a semiconductor laser array chip (3) including a plurality of stripe-shaped active regions (4), each region being independently driven, and a heat sink (2) on which said semiconductor laser array chip (3) is disposed, wherein:

   said heat sink (2) comprising a plurality of layers comprising a material having relatively high thermal conductivity (23) and a plurality of layers comprising a material having relatively low thermal conductivity (24), which are alternately laminated in the array direction of said active regions (4), thicknesses of the respective layers being determined so that a thermal expansion coefficient of the

whole heat sink (2) is equivalent to a thermal expansion coefficient of a principal material of said semiconductor laser array chip (3); and

said semiconductor laser array chip (3) being disposed on said heat sink so that at least one of said relatively low thermal conductivity layers (24) is present beneath each region between adjacent active regions.

3. A semiconductor laser device comprising a semiconductor laser array chip (3) including a plurality of stripe-shaped active regions (4a,4b,4c,4d), each region being driven independently, and a heat sink (2) on which said semiconductor laser array chip (3) is disposed, wherein:

said heat sink (2) including a plurality of stripe grooves (8) having a prescribed depth from the surface of said heat sink (2) and periodically disposed in the array direction of said active regions (4a,4b,4c,4d);

said semiconductor laser array chip (3) being disposed on said heat sink (2) so that each stripe groove (8) is present beneath a region between adjacent active regions; and

said depth being determined so that a distance from one of said active regions of said semiconductor laser chip (3) to the adjacent active region along said stripe groove (8) is longer than a distance from the surface of said heat sink (2) to the rear surface thereof.

4. A semiconductor laser device comprising a semiconductor laser array chip (3) including a plurality of stripe-shaped active regions (4a,4b,4c,4d), each region being driven independently, and a heat sink (2) on which said semiconductor laser array chip (3) is disposed, wherein:

said heat sink (2) including a plurality of stripe-shaped low thermal conductivity regions (11) having a prescribed depth from the surface of said heat sink (2) and periodically disposed in the array direction of said active regions (4a,4b,4c,4d);

said semiconductor laser array chip (3) being disposed on said heat sink (2) so that each low thermal conductivity region (11) is present beneath a region between adjacent active regions; and

said depth being determined so that a distance from one of said active regions of said semiconductor laser chip (3) to the adjacent active region along said low thermal conductivity region (11) is longer than a distance from the surface of said heat sink (2) to the rear surface thereof.

5. A semiconductor laser device comprising a semiconductor laser array chip (3) including a plurality of stripe-shaped active regions (4a,4b,4c), each region being driven independently, and a heat sink (26) on which said semiconductor laser array chip (3) is disposed, wherein:

said heat sink (26) comprising a polycrystalline layer including columnar or fiber grains; and

said semiconductor laser array chip (3) being disposed on a surface of said heat sink (26), which surface is perpendicular to the length of said grain.

6. The semiconductor laser device of one of claims 1 to 5 wherein a plurality of independent semiconductor laser chips, each chip including a stripe-shaped active region, are employed as said semiconductor laser array chip.

7. The semiconductor laser device of one of claims 1 to 6, wherein said insulating material having relatively high thermal conductivity (2a) is diamond and said insulating material having relatively low thermal conductivity (2b) is SiO_2.

8. The semiconductor laser device of one of claims 1 to 6 wherein said laser array chip (3) comprises GaAs, said material having a relatively high thermal conductivity (23) is diamond, and said material having a relatively low thermal conductivity (24) is silver.

9. The semiconductor laser device of one of claims 1 to 8 wherein said low thermal conductivity regions (11) are formed by selectively diffusing an impurity into said heat sink (2).

10. The semiconductor laser device of one of claims 1 to 8 wherein said low thermal conductivity regions (11) are formed by thermally oxidizing portions of said heat sink (2).

11. A method for producing the semiconductor laser device of one of claims 1 to 10 including alternately depositing said relatively high thermal conductivity layers (23) and said relatively low thermal conductivity layers (24) by CVD, sputtering, or vacuum deposition.

FIG.1

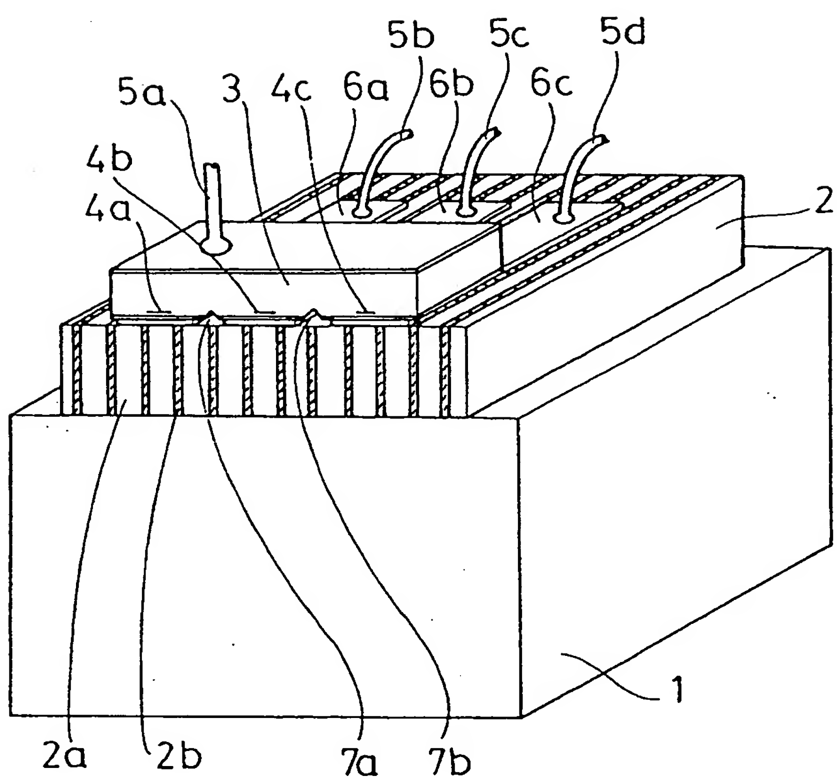


FIG.2 (a)

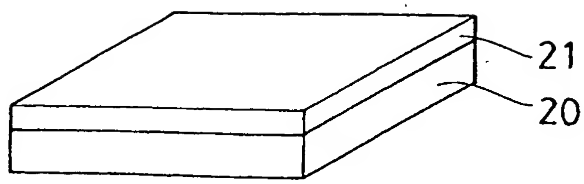


FIG.2 (b)

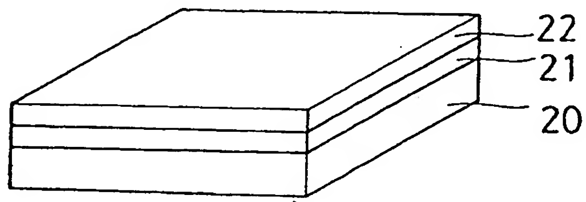


FIG.2 (c)

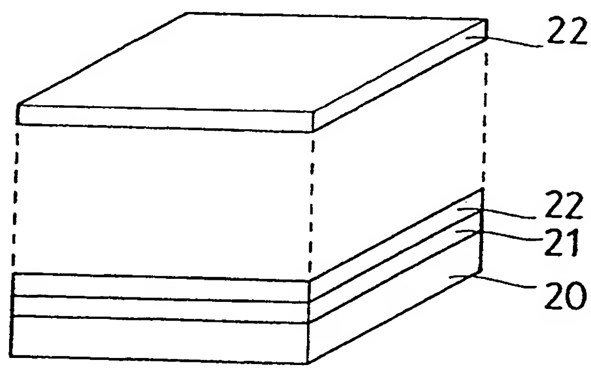


FIG.2 (d)

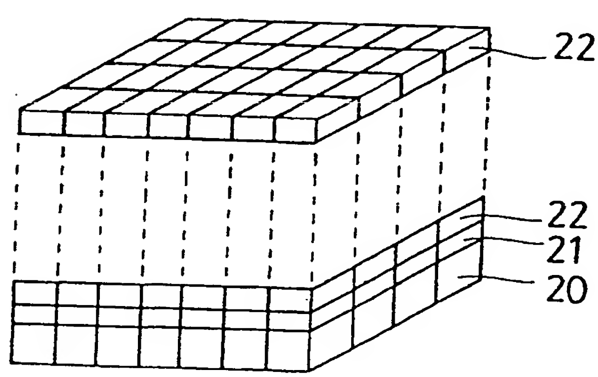


FIG. 3

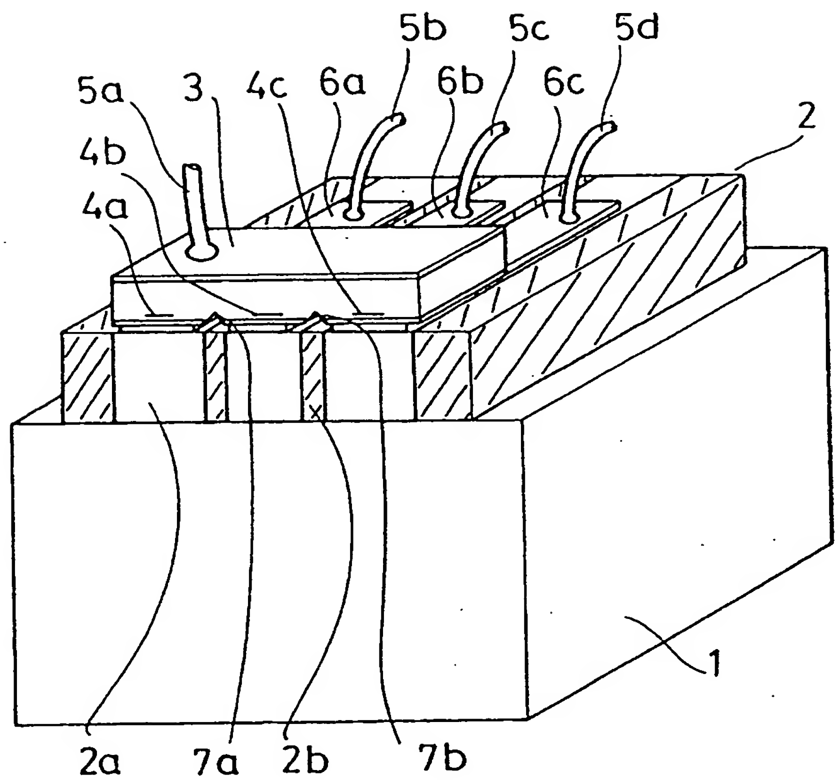


FIG.4

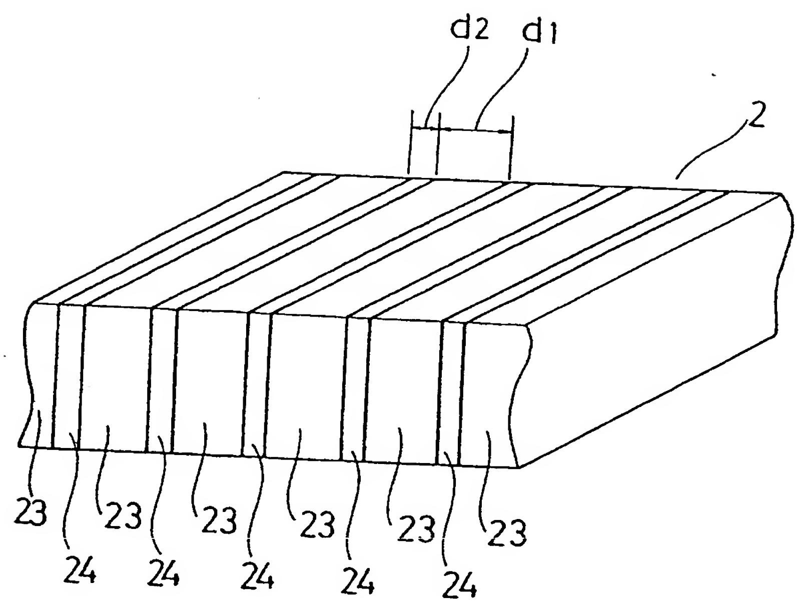


FIG.5

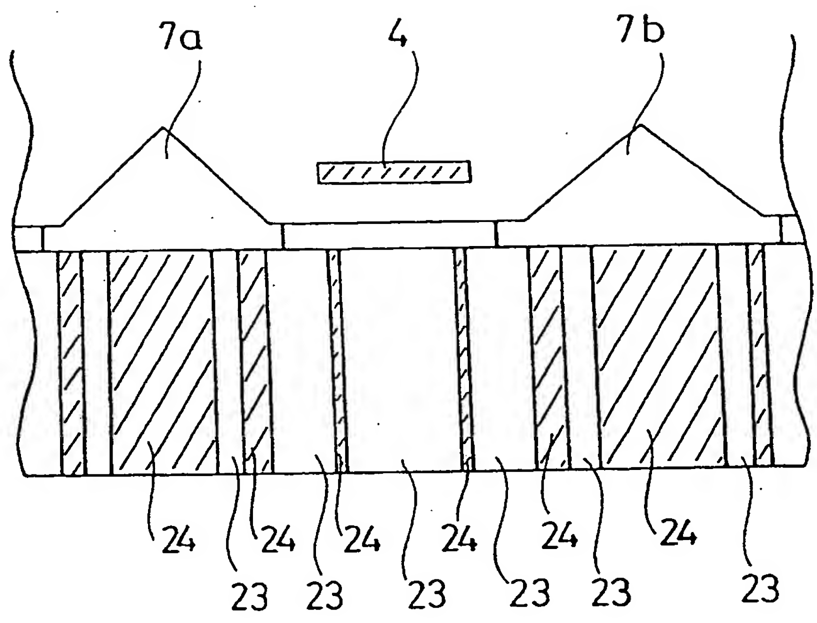


FIG. 6

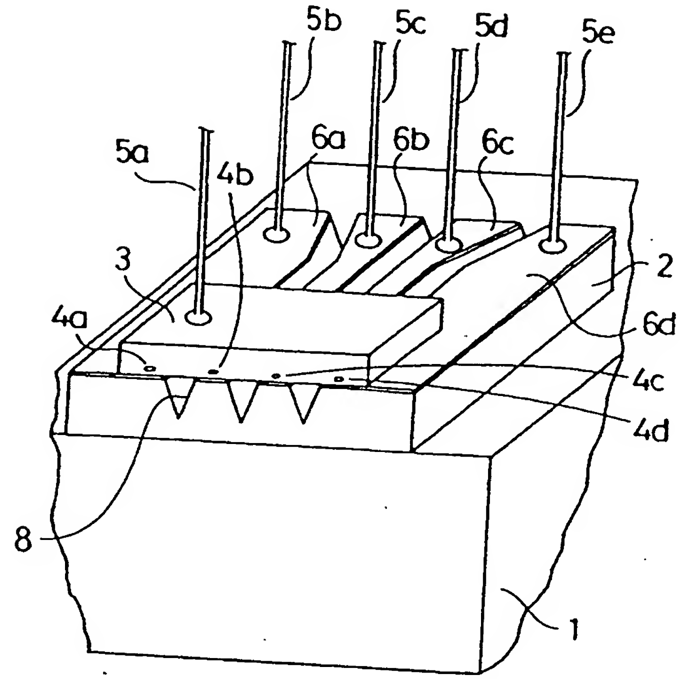

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FIG. 7

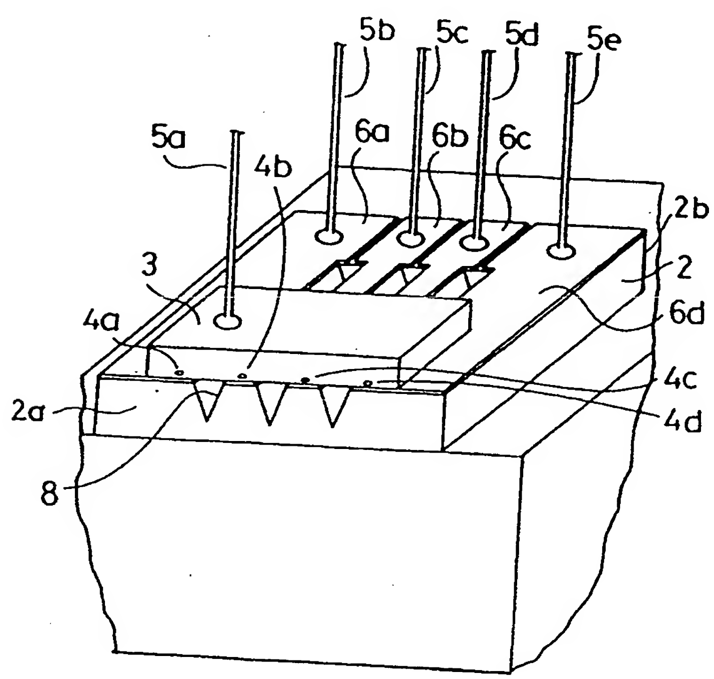
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FIG. 8

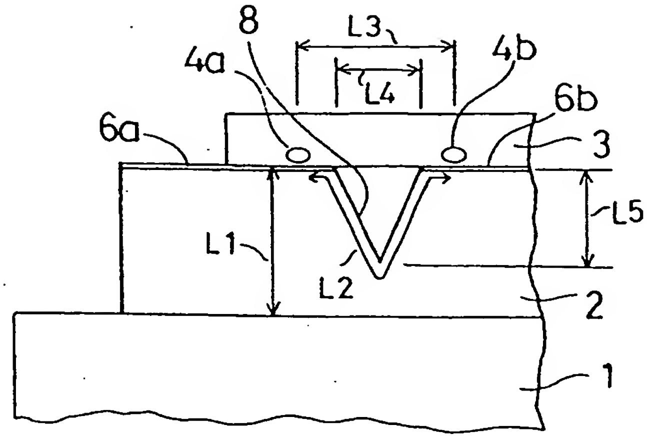

FIG. 9 (a)

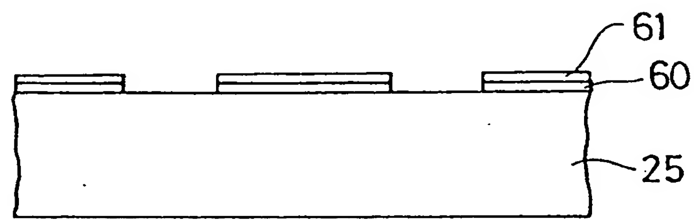

FIG. 9 (b)

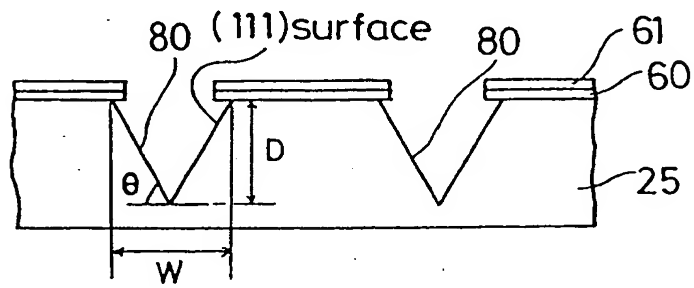

FIG. 9 (c)

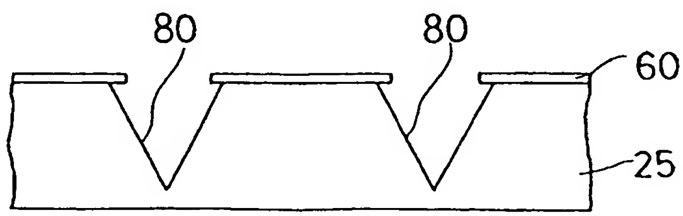

FIG.10

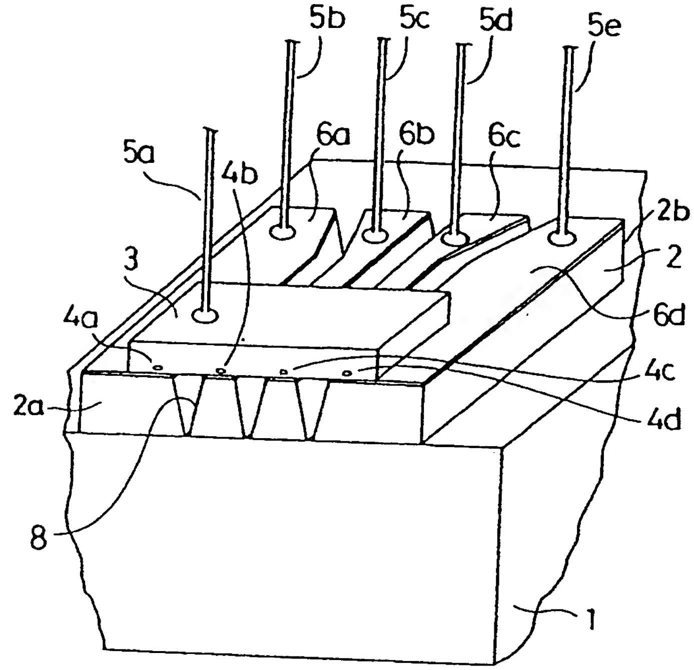
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FIG.11

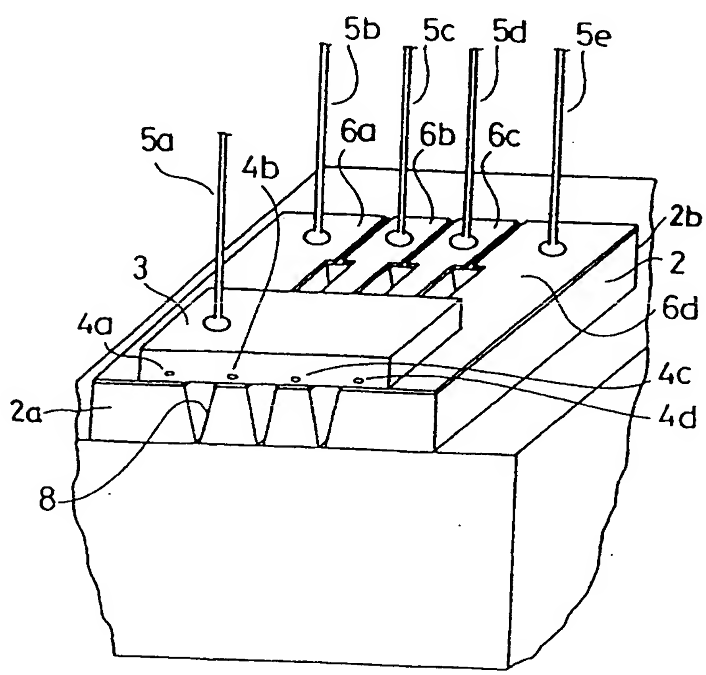
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FIG. 12

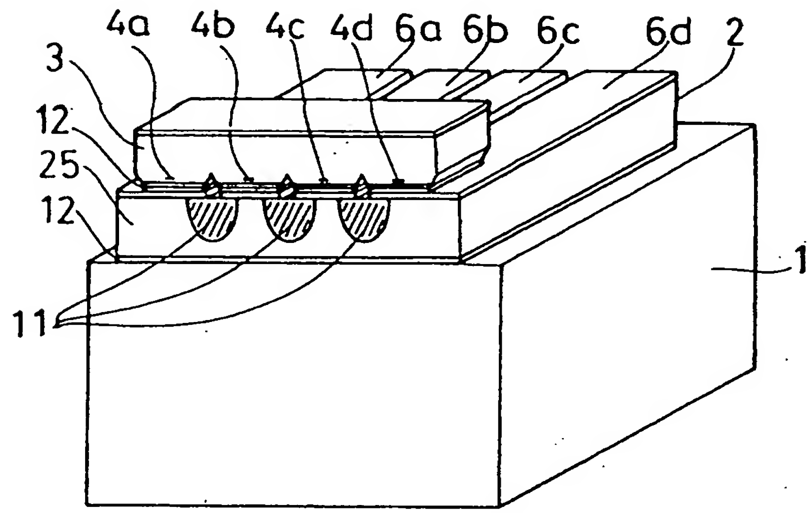


FIG. 13 (a)

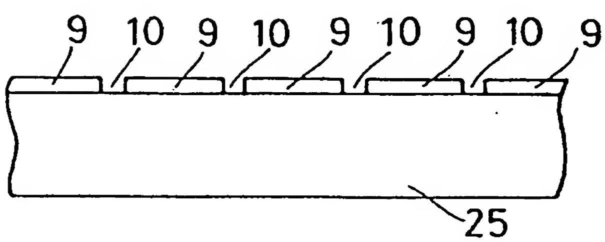


FIG. 13 (b)

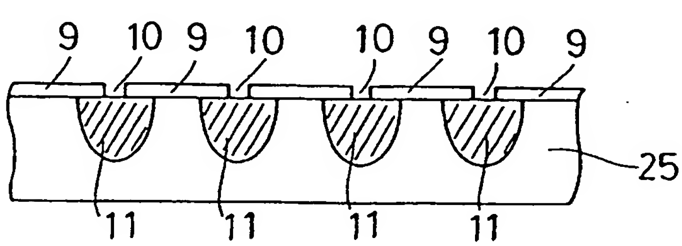


FIG. 14

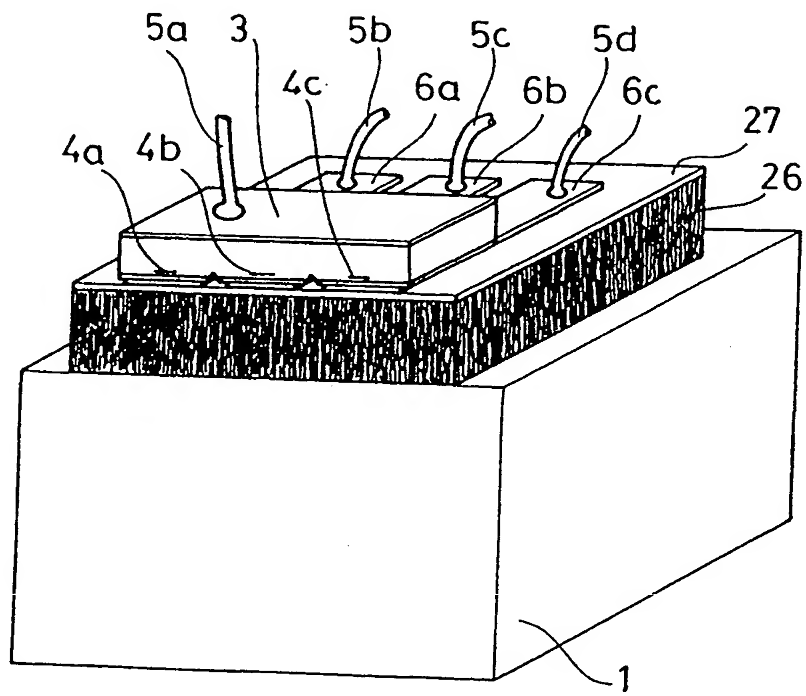


FIG. 15 (a)

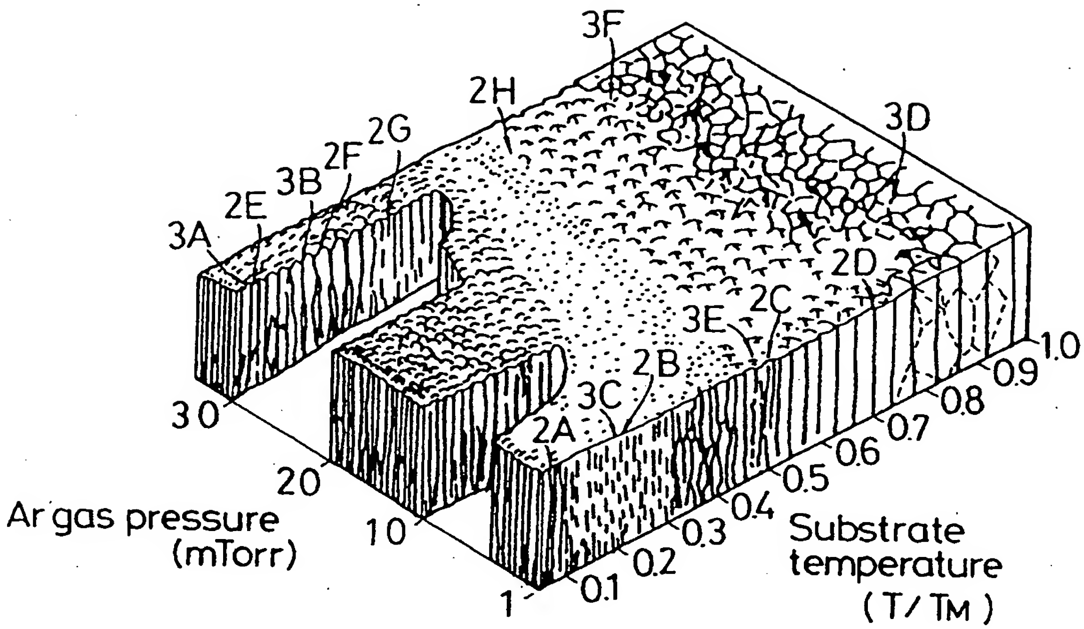


FIG. 15 (b)

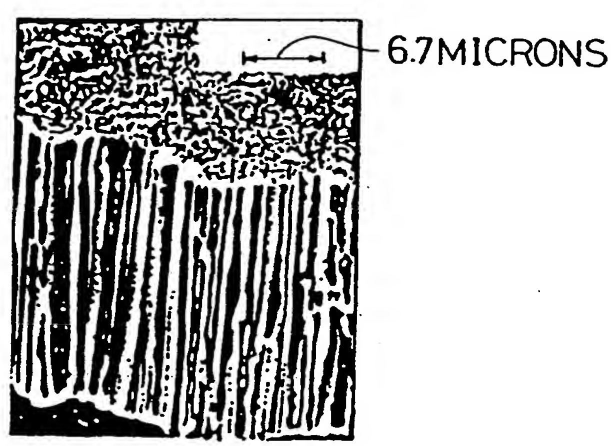


FIG. 16

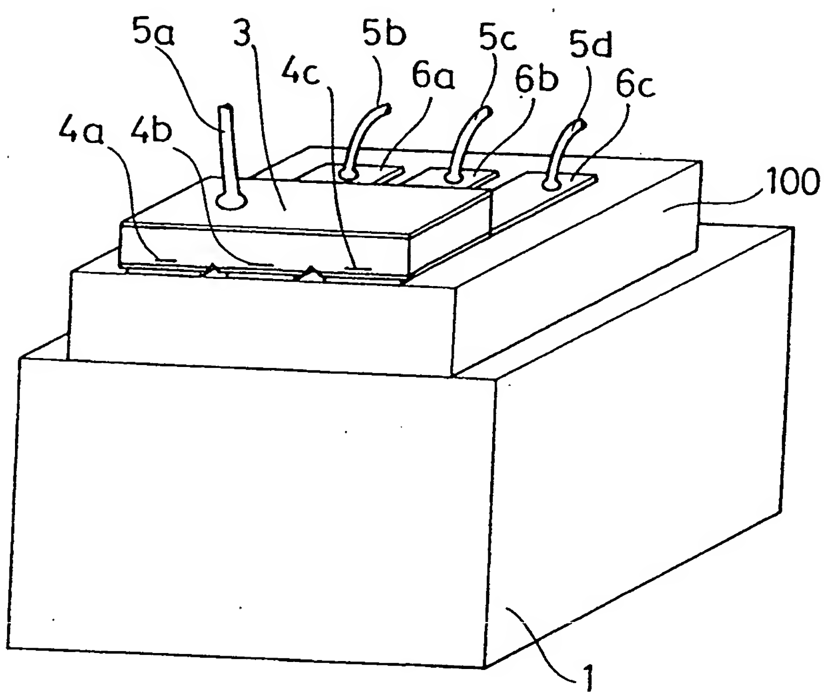
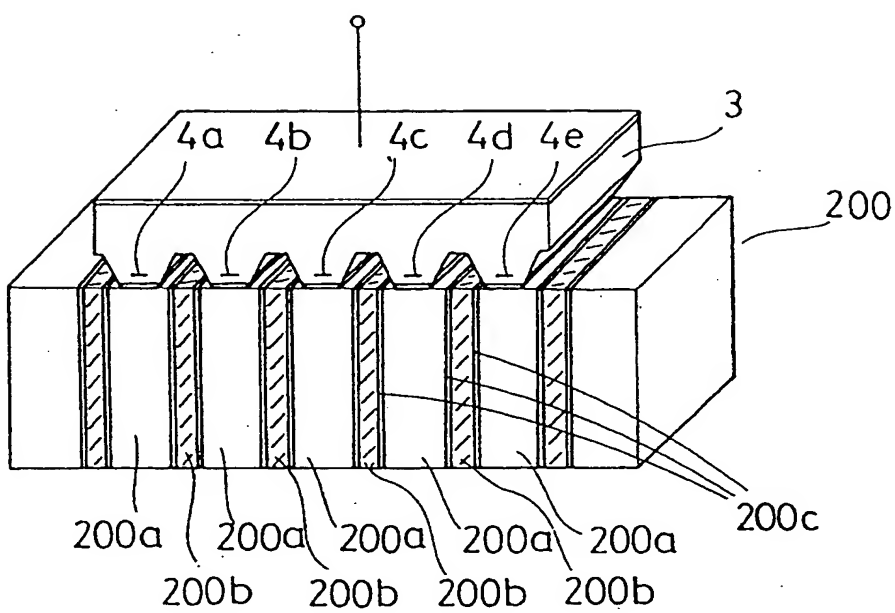


FIG. 17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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 10 4783

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
D,A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 11 (E-374)17 January 1986 & JP-A-60 175 476 (TOSHIBA) 9 September 1985 * abstract *	1,6	H01S3/043 H01S3/25
A	EP-A-0 390 313 (MITSUBISHI) 3 October 1990 * column 1, line 43 - column 2, line 5 * * column 4, line 1 - column 5, line 35; figures 1-6 *	1,2,6-8	
A	US-A-4 069 463 (MCGRODDY ET AL.) 17 January 1978 * column 3, line 39 - column 5, line 24; figure 1 *	1,2,10	
A	PATENT ABSTRACTS OF JAPAN vol. 7, no. 204 (E-197)(1349) 9 September 1983 & JP-A-58 102 590 (FUJITSU) 18 June 1983 * abstract *	3	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
A	EP-A-0 350 327 (XEROX) 10 January 1990 * column 2, line 33 - column 3, line 22 * * column 4, line 54 - column 5, line 34; figure 1 *	4,9,10	H01S
A	PATENT ABSTRACTS OF JAPAN vol. 9, no. 47 (E-299)27 February 1985 & JP-A-59 188 152 (FUTABA) 25 October 1984 * abstract *	5	

-/--

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 January 1994	Stang, I

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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T : theory or principle underlying the invention
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D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 10 4783

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	JOURNAL OF APPLIED PHYSICS vol. 70, no. 9 , 1 November 1991 , NEW YORK, US pages 4715 - 4723 XP274140 S. MURATA, K. NISHIMURA 'A Simple New Laser Diode Array Model for Thermal Interaction Analysis' * paragraphs IIB, VC, VI * -----	7	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 January 1994	Stang, I

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X : particularly relevant if taken alone
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L : document cited for other reasons

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